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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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A photon counting imaging device with fast region of interest data evaluation

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Description

A photon counting imaging device with fast region of interest data evaluation

The invention relates to a photon-counting imaging device for single x-ray counting.

X-ray diffraction patterns are useful in the analysis of molecular structures, such as protein and virus molecules, and require photon counting imaging devices. Especially, protein and virus crystallography imposes stringent requirements on x-ray detectors, particularly where the x-ray source is high flux synchrotron radiation that enables an experiment to be done rapidly. Furthermore, an important and developing field is time-resolved diffraction experiments using synchrotron radiation, such as crystallography and/or powder diffraction analysis. Monitoring a time-dependent reaction in a sample, i.e. a crystal or a powder, can elucidate the time-dependent crystal/molecular changes that occur in a chemical reaction as well. High time resolution speed is often critical in such monitoring.

In the literature, a high speed crystallography detector is disclosed by the US patent 5,629,524 and a solid-state image sensor with focal-plane digital photon-counting pixel array is disclosed by the US patent 5,665,959. The latter patent describes and illustrates a focal-plane array comprising an array of NxN photodetector diodes connected to a digital photon-counting means for ultrlow level image light detection and digital image pixel readout means for each pixel comprising separate CMOS buffer amplifiers that exhibit the following characteristics: low power (< 1 μW per pixel average), high photoelectron charge to voltage conversion

µm), easy scalability (to 10 µm), self biasing capability, sufficient gain uniformity (~ 10%) for multiple event discrimination, and bias current programmability. Any incident photon during the sampling period generates a photoelectron at the output of the detector diode connected to the input of the amplifier. That photoelectron changes the potential of the buffer amplifier's input capacitance. This change in potential causes the high-gain buffer amplifier to present a sufficiently large voltage change at the output of the amplifier to be above the system noise level.

The drawback of this disclosure remains substantially in the design of this photon counting device that is dedicated to detect with brilliant sensitivity a single photon having its energy in the range of the visible light (several eV). This device can therefore be used for infra-red binoculars or for space-based telescopes and spectrometers. The electronic circuitry is therefore that sensitive that an incident photon is amplified in order to saturate the buffer of the amplifier. An additional incident photon occurring in the same photodetector diode within the same sampling period as the first incident photon therefore can not be detected unless the buffer is reset. This photon detecting device is therefore completely useless for the above-mentioned purposes of x-ray photon detection.

Nevertheless, the general design of the semiconductor chip is preferably a hybrid using a separate semiconductor material for two chips selected to be optimum for the photovoltaic type of detector diodes in one and the buffer amplifier and multiplexing circuit in the other chip bump bonded to the first to make connections between the output interface of the detector diodes on one chip and the input interface of the buffer amplifier on the other chip with the photodetector diodes buffer amplifier in one semiconductor chip and the multiplexing means and digital counters on the second semiconductor chip bump bonded to the first. As disclosed in

the US patent 5,629,524 a suitable material for the electrical bump connection is Indium. But even this device for x-ray photon detection can not be used in high dynamic investigation since the electronic circuitry is limited due to the switching dead time that is required to integrate the charge of the photo electrons subsequently to a chain of capacitors (referred to as a M-bit shift register) which have to be read out afterwards serially due to its chain-like arrangement. It could be easily understood that the performance of this circuitry is limited to its switching intervals for charging and scanning the capacitors.

Another prior art document worth to be mentioned is the US patent No. 5,812,191 disclosing a semiconductor high-energy radiation imaging device having an array of pixel cells including a semiconductor detector substrate and a semiconductor readout substrate. The semiconductor detector substrate includes an array of pixel detector cells, each of which directly generates charge in response to incident high-energy radiation. The semiconductor readout substrate includes an array of individually addressable pixel circuits, each of which is connected to a corresponding pixel detector cell to form a pixel cell. Each pixel circuit includes charge accumulation circuitry for accumulating charge directly resulting from high-energy radiation incident on a corresponding pixel detector cell, readout circuitry for reading the accumulated charge, and reset circuitry for resetting the charge accumulation circuitry. Unfortunately, the accumulated charge is stored as analog data using a circuitry having two transistors, one transistor acting as the charge store while the other acts as a readout switch responsive to an enable signal. This design restricts the circuitry to allow individual addressing each pixel but only discharge the accumulated analog charge to an output line when activated by its respective enable signal. This circuitry does not enable any further manipulation of the pixel detector cells.

Another imaging device for imaging radiation according to the international patent application WO 98/16853 includes an image cell array. The image cell array includes an array of detectors cells which generates charge in response to instant radiation and an array of image cell circuits. Each image cell circuit is associated with a respective detector cell. The image cell circuit includes counting circuitry for counting plural radiation hits incident on an associated detector cell. Preferably, the image cell circuit includes threshold circuitry connected to receive signals generated in the associated detector cell and having values dependent on the incident radiation energy. The counting circuitry is then connected to the threshold circuitry for counting only radiation hits within a predetermined energy range or ranges. The electronic readout circuitry is designed to comprise a loadable shift register storing the data serially in a row that means the input data is the data from the previous pixel and the output delivers the actual data to the next pixel. The main drawback of this arrangement consists in the susceptibility to a failure of a complete row of the detector array if only one the readout circuitry in a row fails.

Furthermore, using x-ray diffraction for the analysis of the crystallographic structure of a sample a fast and reliable measurement procedure requires a comparably large detector array for covering a sufficient large spatial area. It is apparent from the required electronic equipment that an increasing number of detector arrays is followed by an increasing number of electronic equiment and/or a prolongated evaluation procedure.

Resuming the prior art document it will be apparent that none of the document disclose a photon counting imaging device that allow high time resolution capabilities in order to detect the time resoluted occurrence of a photon or a

predetermined number of photons in a distinct cell or region in the photodetector diode.

Therefore, it is the aim of the invention to increase the time resolution capabilities of a photon counting imaging device.

This aim is achieved according to the invention by a photon-counting imaging device for single x-ray counting comprising:

a) a layer of photosensitive material;
b) an NxM array of photodetector diodes arranged in said layer of said photosensitive material;
c) an NxM array of readout unit cells comprising an high gain, low noise amplifying means, one readout unit cell for each photodetector diode; the readout unit cells being controlled by a data processing means;
d) each readout unit cell comprising an internal data processing means allowing to assign an output signal representing an amplifyied signal of the electron hole pairs generated by an incident photon or a predetermined number of incident photons in the respective photodetector diode to a preselectable region of interest; and
e) said assignment of the output signal is accompanied by a time stamp generated by a clock means.

Due to this measures beside the normal operation of the photon counting imaging device the output signal generated by the amplifying means can be treated separately with respect to the occurrence of the photon hitting the respective photodetector diode. For that reason, the time resolution at least for this preselected region of interest, that could consist of one distinct photodetector diode only or of a number of adjacent photodetector diodes, is enhanced as far as the clock means allow this resolution with an appropriate frequency. Hereby, the clock means can be realized as a counter being pulsed with a specific frequency; for example,

a pulse frequency of 100 MHz yields to a possible time resolution of 10 ns. The time stamp therefore is derived by the actual standings of the counter when a photon hits a photodetector diode being part of a preselected region of interest and the simultaneous output signal occurrs.

A proper design of the photon-counting imaging device may understand each readout unit cell to comprise an input interface connected to said diode output interface, a high-gain voltage amplifying means comprising a comparator unit, a digital counter unit, comprising a digital counter, and a digital counter output interface connected in series, each digital counter unit counting the output signal of the comparator unit; said output signal is additionally directed to a region of interest unit; said region of interest unit being part of the readout unit cell or being part of the external data processing means. The advantage of a region of interest unit being part of the readout unit cell consist in the processing of the region of interest data on chip and therefore only the output of the readout unit cells being part of the predeterimed regions of interest have to observed.

Again, in order to design the photon-counting imaging device in an consequential and easy manner, it may comprise at least one predeterminable region of interest, whereby a preselectable number of selectable photodetector diodes represent this region of interest;
the output signal in each elected corresponding readout unit cell being processed to the respective region of interest unit causing the output interface corresponding to the region of interest hit by an incident photon to set a region of interest hit signal;
said region of interest hit signal is aligned by the time stamp originated by an external or an internal clock means. Additinally, it seems to be most suitable to have the data processing means providing a means for storing either the

time stamp or an information comprising the time stamp and the corresponding regions of interest which was hit by an incident photon originally causing the output signal. The first alternative takes it as granted that a specific part of the means for storing offer a distinct volumen dedicated to store the time stamps for a distinct region of interest only. The second alternative requires a bit more available storage space because each data entry comprises the time stamp and the region of interest information.

For region of interest in which x-rays are hitting the detector diode too frequently to store the arrival time (which is represented by the time stamp) of each photon separately, additional electronics can be implemented in each readout unit cell to generate the region of interest hit signal only after a programmable number of photons have hit the region of interest channel. Therefore, it may be appropriate to design the region of interest unit as to comprise a counter means for which a region of interest hit signal set threshold is determinable.

In order to achieve a sufficient time resolution the counting of the clock means should be initiated with the initial start of an experiment or a sample period. Therefore, it is useful when the external or the internal clock means can be reset and operates with a frequency in the range of 10 to 500 MHz, preferably about 100 MHz. The latter frequency yields to a time resolution of about 10 ns, which allows conveniently to observe even very fast changements in the crystalline structure of a probe.

For some of the possible investigations with the photon-counting imaging device, it may be very interesting to change the defined regions of interest during a measurement cycle, may be due to an assumed change of the crystalline structure or for other reasons. Therefore, the device is designed to allow the definition of a number of at least two regions of

interest are provided, each of the at least two regions of interest having a programmable time-related validity. This may have in detail the meaning that the region of interest migrate as a function of the time. Therefore, at least an initial region of interest have to be predetermined and a time related function for the migration of the region of interest. Therefore, also this example is to be understood when the claim language mentions that at least two regions of interest are provided.

Examples of the invention are described below in accordance with the drawings which depict:

Figure 1 a schematic view of a photodetector diode;

Figure 2 a schematic view of a part of a sensor module comprising an array of photodetector diodes as one of them is shown in Figure 1;

Figure 3 a schematic view of a microstrip detector;

Figure 4 a schematic view of the readout electronic of a readout unit cell assigned to and connected with a photodetector diode as shown in Figur 1;

Figure 5 a sensor module as a basic element for a photon-counting imaging device having a number of those sensor modules with a sensor module control board;

Figure 6 a schematic view on a sensor module readout process;

Figure 7 a schematic view on photons entering the microstrip detector according to figure 3;

Figure 8 a schematic view of the signals caused by the photons as shown in figure 7 entering the microstrip detector; and

Figure 9 a detailed blockdiagram of an enhanced readout unit cell as shown in figure 4.

Figures 1 illustrates schematically the architecture of a photodetector diode 2 having a doped semiconductor p^+, n^+, n^{++} trespassing section 4. The material choosen for the photodetector diode 2 depends on the desired bandgap energy required to generate an electron hole pair by the photo-effect. Suitable materials are undoped amorphous silicon having band gap of 1.12 eV and a bundle of IV-IV compounds and III-V compounds (indium and gallium salts, like gallium arsenide or indium antimonide).

An incident photon 6 having an energy in the range of several KeV before entering the doped semiconductor p^+, n^+, n^{++} trespassing section 4 passes through an aluminium cover layer 8 and causes according to its energy and to the energy gap of the doped semiconductor p^+, n^+, n^{++} trespassing section 4 a respective number of electron hole pairs 10 under x-ray annihilation. In the drawings, this number of electron hole pairs is exemplarily shown by one electron-hole pair 10 being divided by the electrical field generated by a source of bias potential 12. The evaluation of the charge occurred from the electron hole pairs 10 will be described below with reference to figure 4.

Figure 2 shows a schematical view of a two-dimensional pixel detector 14 having a number of photodetector diodes 2 arranged in an array of 22 rows and 32 columns (compare figure 6).The photodetector diodes 2 have a length l and a width w of about 200 µm and a height of about 300 µm. Below the plane of these photodetector diodes 2 a readout chip 16 having a corresponding number of readout unit cells 18 is

arranged for collecting the charge from the electron hole pairs 10 generated in the respective photodetector diodes 2. The electrical conjunction between a diode output interface 20 of the photodetector diodes 2 and an input interface 22 of the readout unit cells 18 is achieved by bump bonding using indium bumps 24.

Figure 3 depicts a schematical view of a microstrip detector 26 having on a hybrid support 28 arranged a number of thirty-eight strip-type photodetector diodes 30 build in a microstrip sensor sector 32 of the hybrid support 28. The strip-type photodetector diodes 30 have a width of about 15 µm, a length of about 8 mm and a pitch of about 50 µm. Next to the microstrip sensor sector 32 a microstrip readout sector 34 is arranged having a number of readout unit cell 36 (not shown in detail, described below) corresponding to the number of strip-type photodetector diodes 30. These readout unit cells 36 are connected with their input interface 22 to the photodetector diodes 30 by bond pads 38 which additionally connect an output interface 40 of the readout unit cells 36 to a digital counting sector 42 which is described below, too. Due to the very limited width of the strip-type photodetector diodes 30 the spatial resolution achievable in one dimension is superior over the spatial resolution of the array-type two dimensional pixel detector 14.

Figur 4 now depicts a schematic view of a electronic readout equipment 44 as it can be used for both the two-dimensional pixel detector 14 and the microstrip detector 26. The electronic readout equipment 44 is divided into an analog block 46 and a digital block 48. The analog block 46 starts with the bump pad 22 (interface), 38 resp. connected to an input terminal of a charge sensitive amplifier Amp. For calibration purposes, a source of calibration voltage U_{Cal} is connected via a capacitor C to the input terminal of the amplifier Amp, too. The capacity of the capacitor has been

chosen to a comparably tiny capacity of about only 1.7 fF allowing to be sensitive enough that the photo-electrons can change the voltage over the capacitor C to an extend that this difference can be significantly amplified by the amplifier Amp hereinafter referred to as first output voltage signal.

This first output voltage signal is led to one of the two input terminals of a comparator amplifier CA which is additionally connected to a source of a threshold voltage supply U_T. The other input terminal of the comparator amplifier CA is additionally connected to a source of threshold voltage correction supply TC. This source of threshold voltage correction supply TC allows to bias the input terminals of the comparator amplifier CA. According to the predetermined bias of the input terminals of the comparator amplifier CA even the first output voltage signal from the CS amplifier Amp that represents a fractional part of the charge of the generated photo-electron hole pairs only can be further processed and is therefore not lost for the successive data processing and evaluating.

This electronic readout equipment 44 enables the detection of fractions of the full charge of the photo-electron hole pairs 10 generated by an incident x-ray what may occur when the photo-electron hole pairs 10 are generated in the twilight zone located between two adjacent photodetector diodes 2 what will be described below with reference to the figures 7 and 8.

As an example, the source of threshold voltage correction supply TC can be adjusted up to a level defined by one half of the full charge of the photo-electron hole pairs 10 generated in total by one x-ray photon. Consequentially, the distribution of the charge of the photo-electrons to adjacent photodetector diodes 2 can be further processed. A downstream data processing unit is now enabled to perform a differential

evaluation of the digital output voltage signals of the comparators having its origin from the photo-electrons in adjacent photodetector diodes 2, whereby these photo-electrons have been generated by the same x-ray photon.

Downstream to the analog block 46 is the digital block 48 having generally the task to convert the digital output voltage signal into a digital counter signal that can be evaluated by multiplexing means MM provided with the data processing means DPM. Together with a enable/disenable switch E/D different clock means, i.e. an external clock RCLK from the data processing means DPM control a clock generator CG for a digital counter unit SRC which itself is connected to a readout bus output RBO. The digital data stored in the digital block 48 of a distinct readout unit cell can then be readout if a row select RS and column select CS are set high to set high an AND-gate &.

Figure 5 illustrates a solid-state photon-counting imaging device 50 detecting the photon radiation over a comparably large flat area. The present architecture combine a number of sixteen pixel sensors 14 being arranged on a first substantially flat support plate 52 for building a sensor module 54, and a sensor module control board 56 being arranged on a second substantially flat support plate 58 hosting the electronic evaluation equipment, i.e. multiplexing means MM, data processing means DPM, which follow the afore-mentioned electronic readout equipment 44. The first substantially flat support plate 52 and the second substantially flat support plate 58 being arranged under an angle of 90°. This measure allows to construct a plane or curved detector surface area (here not shown in the drawings) made from a number of sensor modules 54 having the sensor module control boards 56 oriented to the opposite side of its detector surface.

Figure 6 now shows a schematic view on a sensor module readout process indicating that appropriate multiplexing means MM allowing with a row select logic RS and a column select logic CS to address a predetermined readout unit cell 18 in order to readout the value of the digital counter SRC. This addressability lead to the capability of the complete photon-counting imaging device 50 to access and/or control continiously or temporarily each readout unit cell. The photon-counting imaging device 50 owns the capability to access and/or control via the data processing means DPM via the multiplexing means MM one or more of the following issues:

a) programming of the readout unit cell via a port DIN;
b) readout of the data in the readout unit cell via a port DOUT;
c) calibration of the readout unit cell, preferably the high gain voltage amplifier means 46, via a port CAL; and
d) analyzing the analog signal in the high gain voltage amplifier means 46 for the purpose of diagnosis via a port AOUT.

All the afore-mentioned ports DIN, DOUT, CAL and AOUT are comprised in the readout bus RB that is controlled by the data processing means DPM. With respect to the multiplexer means MM, it has to be pointed out additionally that this multiplexer means MM is substantially a separate chip being located on the sensor module control board 56. This separate chip generates a chip select for at least one or all of the readout chips assigned to each of the pixel sensors 14. Each readout chip itself comprises a column select shift register and a row select shift register for selecting a distinct sensor pixel. Therefore, in principal the multiplexing means MM are assigned to both each readout chip and the sensor module control board 56.

Additionally, figure 6 depicts a region of interest ROI consisting of nine photodetector diodes 2 what will be described below with figure 9 in detail.

Figures 7 and 8 are now used to introduce the afore-mentioned concept of charge sharing in the microstrip detector 26 allowing the enhancement of the position resolution for the incident photon 6 entering into the doped semiconductor p^+, n^+, n^{++} trespassing section 4. Dotted lines shall indicate the electric field line of the bias potential 12 enabling to collect the photo-electrons at the anode of the photodetector diode 2 as schematically shown in figure 7. Two of the photodetector diodes 30 and their respective readout unit cells 36 are hereinafter referred to as a first channel Ch1 and a second channel Ch2.

In the drawings according to figure 8, the situation with respect to the potentials caused by the incident photons 6a, 6b and 6c is shown. The charge of the electron-hole pairs 10 generated by the photons 6b and 6c absorbed in the doped semiconductor p^+, n^+, n^{++} trespassing section 4 in an intermediate region 60 between the two channels Ch1 and Ch2 is divided over these two channels Ch1 and Ch2 according to the position of the photons 6b and 6c. The charge is shared to the two channels Ch1 and Ch2 and both channels Ch1 and Ch2 show an analogue pulse at the output of the charge sensitive amplifier Amp as it can be seen from figures 8b and 8c.

The pulses after the amplifier Amp (going into the comparator CA) for the photons 6a, 6b, 6c are shown in figure 8a, 8b and 8c resp. Depending on setting of a threshold voltage V_{Thresh} in the comparator CA, a certain risk occurs that the photons 6a, 6b and 6c are counted twice ($V_{thresh} < A_{max}/2$) or not at all ($V_{thresh} > A_{max}/2$). Both effects are highly undesirable and double counting is a serious problem for diffraction experiments.

It is therefore advantageous to implement in the data processing means DPM a logic that prohibits double counting for low threshold voltages ($V_{thresh} < A_{max}/2$). The logic to avoid double counting can easily be implemented using the fact that the output signal OS of the comparator CA for the pulse with the higher amplitude completely encloses the output signal of the comparator CA for the neighbouring channel with the lower amplitude as this can been seen in figure 8b. Figure 8b represents the distribution of the photoelectrons caused by the photon 6b that enters the intermediate region 60 a bit more on the side of the second channel Ch2. The pulse therefore generated in the second channel Ch2 exceeds the respective pulse in the first channel Ch1.

Therefore, the output signal OS of the comparator CA of the channel with the higher amplitude, here the second channel Ch2, can be used to disenable the adjacent channel, here the first channel Ch1, showing the lower signal amplitude. Double counting is therefore avoided by disenabling the weaker channel. I.e. using the output signal OS of the comparator CA of a dominating channel to disenable the comparator CA via the Enable/Disenable Switch E/D (or the counting) of its two neighbouring channels provided the coincidently occurring amplitude of the central channel is above the threshold.

The effect of the charge sharing over two adjacent channels can also be used advantageously to improve the position resolution above the position resolution given by the patterning of the photodetector diodes 30. For example, this can be done by introducing intermediate channels in the readout electronics which either have a special analogue part summing the analogue signals from the two neighbours for restoring the full charge of the electron hole pairs caused by photons entering the intermediate region, or by avoiding completely the analogue part for the intermediate channel, to design a virtual intermediate channel that only counts in case both the comparators CA of both neighbours give a

coincident pulse that reaches in total substantially the level of the full charge of a photon completely absorbed in one channel. In the case of analogue summing a scheme like the one given above can be used to avoid double counting.

In the latter case either additional logic has to be implemented to avoid counting of the neighbours or, even easier, since the intermediate channel only counts if both neighbours count, the counter value of the intermediate channel can just be subtracted from both neighbours. This can be done off line. For the enhancement of the resolution the threshold voltage V_{Thresh} has to be in the range $0<V_{thresh} < A_{max}/2$, preferably closer to $A_{max}/2$ than to zero.

Figur 9 now in detail illustrates the design of the electronic equipment 44 of the readout unit cells 18, 36. Again the analog part 46 is shown comprising the low noise, high gain amplifier Amp and the comparator COMP. The analog part 46 is thereby shown in a shaded manner. Any other component shown in this figure 9 contributes to the digital part 48. Additionally to the schematic view according the figure 4, the controlling of the analog part 46 is represented by a Calibration and threshold correction unit DAC + LATCH which on the one hand side controls a calibration switch CALSWITCH and on the other hand side sets the voltage level for the supply of threshold voltage correction TC. The calibration and threshold correction unit DAC + LATCH is addressed by both setting the AND-gate for the column select CS and the row select RS and the AND-gate for latch programming PRGL to "High" (logically to "1").

Within the normal counting operation, the output signal OS is processed with the pulse generator and the counter SRC. With respect to the selection of a specific region of interest ROI as shown in Figur 6, the signal after the pulse generator PG is processed to a region of interest unit ROI SEL that can be programmed by a port PRG_ROI. The region of interest unit ROI

SEL so far administrates the incoming signal from the pulse generator PG and assigns these signals to the predefined region of interest ROI. By the way, it should be mentioned that a number of different regions of interests ROI(0,…,K) can be predetermined although only one region of interest is shown in figure 6. The assignment is made by setting an output signal to the respective region of interest output interface $ROI(0,\ldots,K)_{out}$ which is connected to the data processing means DPM. The occurrence of this output signal is accompanied by a time stamp which is stored to the data processing means DPM with reference to the respective region of interest ROI. In this manner, the time stamps represent the occurrence of the incident photons 6 in the preselected region of interest ROI. Therefore, a significant higher time resolution for the arrival time of the photons hitting the pixel detector 14 or the microstrip detector 26 in the region of interest ROI. For generating the time stamps, a clock can be used realized as a counter pulsed with a specific frequency, e.g. 100 MHz for a desired time resolution of 10 ns. The clock can be reset at the beginning of the experiment to define the time $t_0 = 0$.

As it can be seen from figure 6, the region of interest ROI consist of an 3x3 array of photodetector diodes 2. It should be mentioned that, alternatively, a region of interest may be even larger or even smaller up to only one photodetector diode 2.

List of reference number

2	Photodetector diode
4	Doped semiconductor p^+, n^+, n^{++} trespassing section
6	Photon
6a, 6b, 6c	Photons
8	Aluminium cover layer
10	Electron hole pairs
12	Source of bias potential
14	Pixel detector
16	Readout chip
18	Readout unit cells
20	Diode output interface
22	Input interface
24	Indium bumps
26	Microstrip detector
28	Hybrid support
30	Strip-type photodetector diodes
32	Microstrip sensor sector
34	Microstrip readout sector
36	Readout unit cells
38	Bond pads
40	Output interface
42	Digital counter section
44	Electronic readout equipment
46	Analog block
48	Digital block
50	Solid-state photon-counting imaging device
52	First substantially flat support plate
54	Sensor module
56	Sensor module control board
58	Second substantially flat support plate
60	Intermediate region
A_{max}	Average amplitude
Amp	Charge sensitive Amplifier
C	Capacitor

CA, COMP	Comparator amplifier
CAL	Calibration voltage
CALSWITCH	Switch for calibration voltage
CG	Clock generator
Ch1, Ch2	First channel resp. second channel of two adjacent readout unit cells
CS	Column select
DAC + LATCH	Calibration and threshold correction unit
E/D	Enable/Disenable Switch
MM	Multiplexing Means
OS	Output signal
PG	Pulse generator
PRGL	Port for programming the DAC + LATCH
PRG_ROI	Port for programming the ROI SEL
RB	Readout bus
Reset	Digital counter reset
ROI	Region of interest
ROI SEL	Region of interest unit
$ROI(0,\dots,K)_{out}$	Region of interest output interface
RS	Row select
SRC	Digital counter unit
t	Time
TC	Source for threshold voltage correction supply
U_{Cal}	Source for calibration voltage
U_T	Source for threshold voltage supply
V_{Thresh}	Threshold voltage

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Patent Claims

1. A photon counting imaging device (14, 26, 50) for single x-ray counting comprising:
   a) a layer of photosensitive material (4);
   b) an NxM array of photodetector diodes (2, 30) arranged in said layer of said photosensitive material (4);
   c) an NxM array of high gain, low noise readout unit cells (18, 36), one readout unit cell (18, 36) for each photodetector diode (2, 30); the readout unit cells (18, 36) being controlled by a data processing means (DPM);
   d) each readout unit cell (18, 36) comprising an internal data processing means (ROI SEL) allowing to assign each output signal (OS) representing an incident photon (6) or a predetermined number of incident photons (6) in the corresponding photodetector diode (2, 30) to a preselectable region of interest (ROI); and
   e) said assignment of the output signal is accompanied by a time stamp.

2. A photon counting imaging device (14, 26, 50) according to claim 1, characterized in that
each readout unit cell (18, 36) comprises an input interface (22) connected to said diode output interface (20), a high-gain voltage amplifying means (46) comprising a comparator unit (CA, COMP), a digital counter unit (48), comprising a digital counter (SRC), and a digital counter output interface (RB) connected in series, each digital counter unit (48) counting the output signal (OS) of the comparator unit (CA, COMP);
said output signal (OS) is additionally directed to a region of interest unit (ROI SEL); said region of interest unit (ROI

SEL) being part of the readout unit cell (18, 36) or being part of the external data processing means (DPM).

3. The photon-counting imaging device (14, 26, 50) according to claim 1 or 2, characterized in that at least one predeterminable region of interest (ROI) is comprised, whereby a preselectable number of elected photodetector diodes (2, 30) build this region of interest (ROI); the output signal (OS) in each elected corresponding readout cell unit (18, 36) being processed to a region of interest unit (ROI SEL) causing the output interface ($ROI(0,\dots,K)_{out}$), corresponding to the region of interest (ROI) hit by an incident photon (6) to set a region of interest hit signal; said region of interest hit signal is aligned by the time stamp originated by an external or an internal clock means.

4. The photon-counting imaging device (14, 26, 50) according to claim 3, characterized in that the data processing means (DPM) provides a means for storing either the time stamp or an information comprising the time stamp and the corresponding regions of interest (ROI) which was hit by an incident photon (6) originally causing the output signal (OS).

5. The photon-counting imaging device (14, 26, 50) according to claim 3 or 4, characterized in that the region of interest unit (ROI SEL) comprises a counter means for which a threshold for setting a region of interest hit signal is determinable.

6. The photon-counting imaging device (14, 26, 50) according to any one of the claims 3 to 5, characterized in that the external or the internal clock means are resetable and operates with a frequency in the range of 10 to 500 MHz, preferably about 100 MHz.

7. The photon-counting imaging device according to any one of the preceding claims,
characterized in that,
a number of at least two regions of interest (ROI) are provided, each of the at least two regions of interest (ROI) having a programmable time-related validity.

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CH-5232 Villigen PSI

Abstract

It is the aim of the invention to increase the time resolution capabilities of a photon counting imaging device.

This aim is achieved according to the invention by a photon-counting imaging device for single x-ray counting comprising:

a) a layer of photosensitive material;

b) an NxM array of photodetector diodes arranged in said layer of said photosensitive material;

c) an NxM array of readout unit cells comprising an high gain, low noise amplifying means, one readout unit cell for each photodetector diode; the readout unit cells being controlled by a data processing means;

d) each readout unit cell comprising an internal data processing means allowing to assign an output signal representing an amplifyied signal of the electron hole pairs generated by an incident photon or a predetermined number of incident photons in the respective photodetector diode to a preselectable region of interest; and

e) said assignment of the output signal is accompanied by a time stamp generated by a clock means.

Due to this measures beside the normal operation of the photon counting imaging device the output signal generated by the amplifying means can be treated separately with respect to the occurrence of the photon hitting the respective photodetector diode. For that reason, the time resolution at least for this preselected region of interest is enhanced as far as the clock means allow this resolution with an appropriate frequency.

Fig. 9

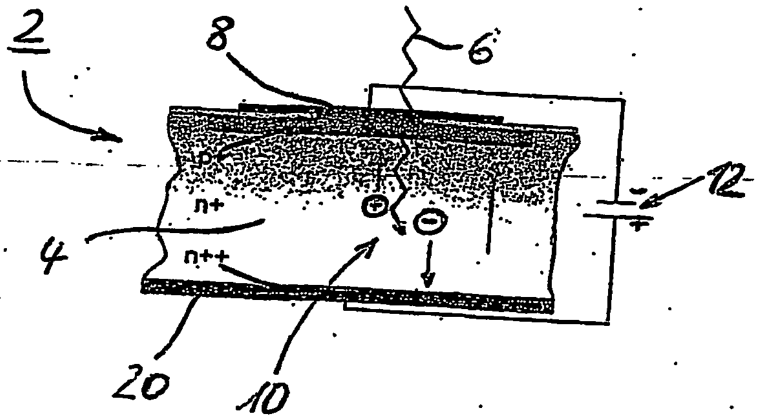

Fig. 1

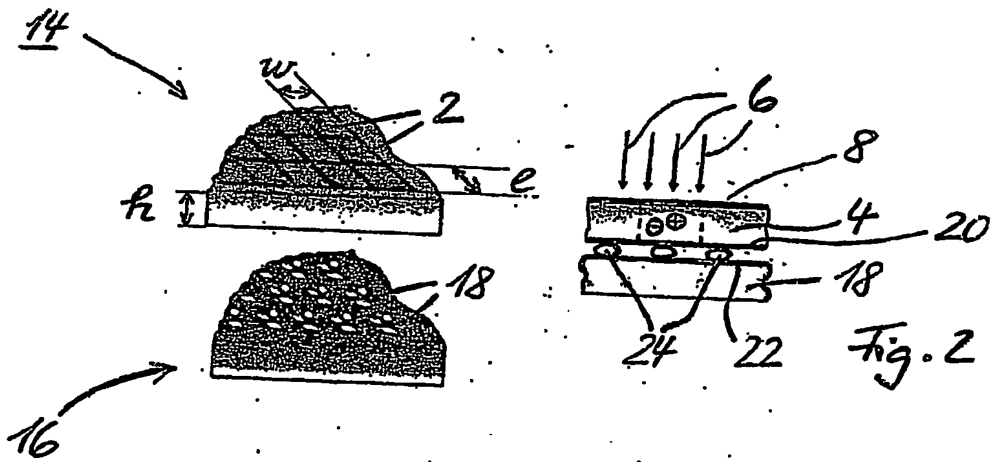

Fig. 2

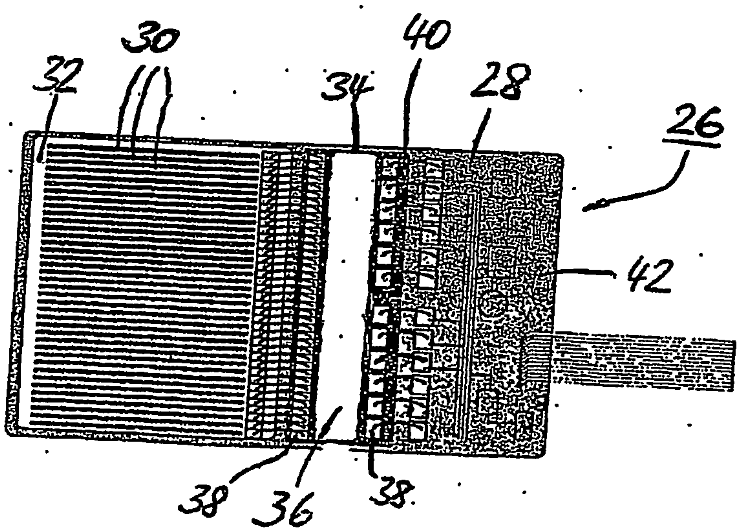

Fig. 3

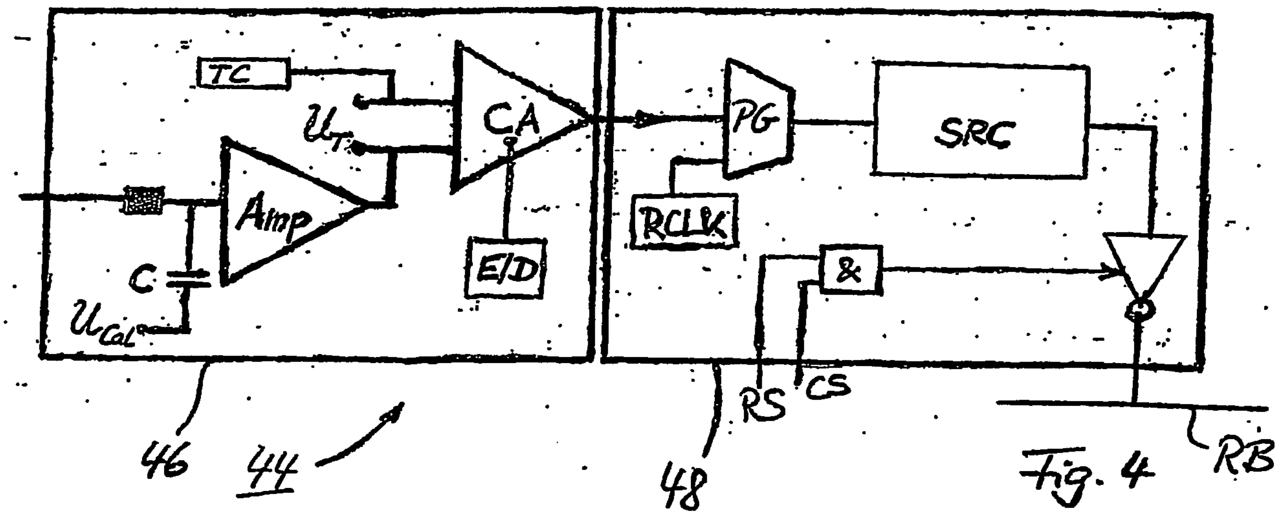
TC
U_T
CA
Amp
C
U_{Cal}
E/D
PG
SRC
RCLK
&
RS
CS
RB
46
44
48

Fig. 4

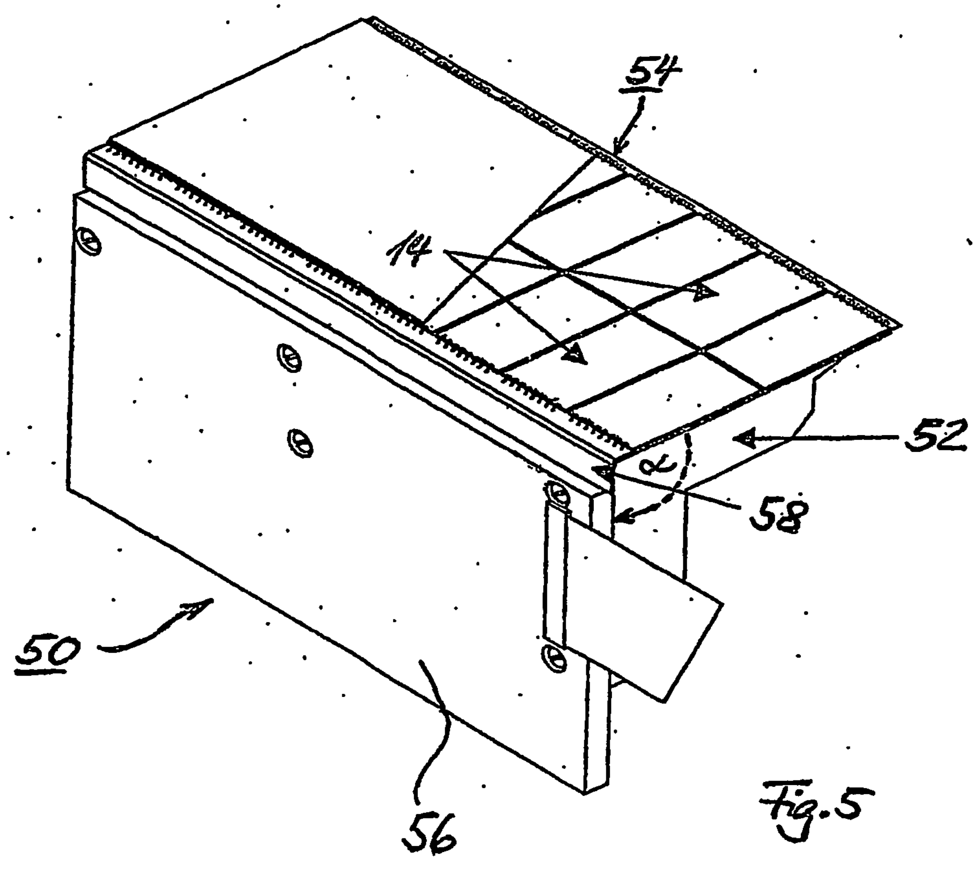
54
14
52
58
α
50
56

Fig. 5

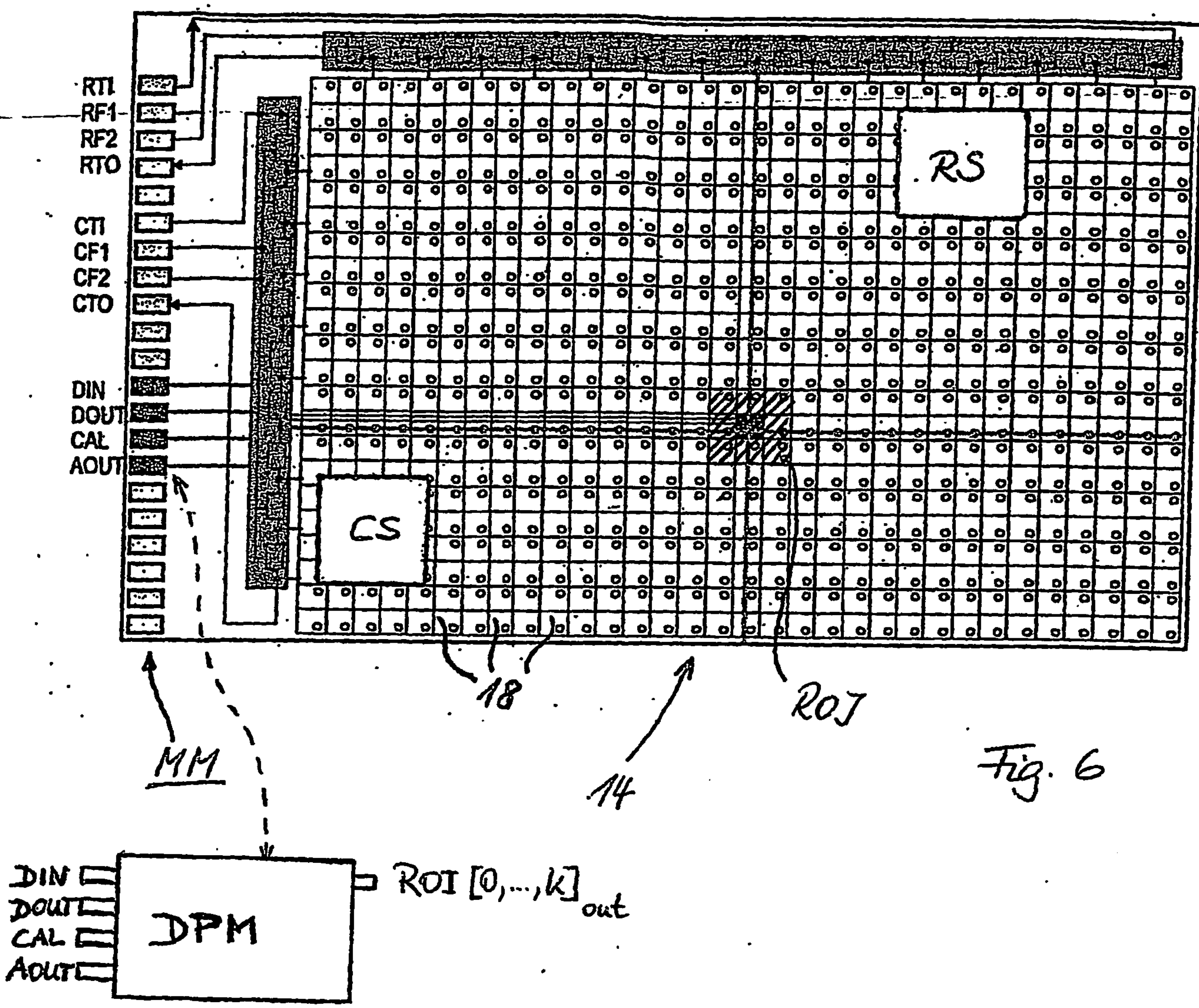
RTI
RF1
RF2
RTO
CTI
CF1
CF2
CTO
DIN
DOUT
CAL
AOUT
RS
CS
18
ROI
MM
14
DIN
DOUT
CAL
AOUT
DPM
ROI [0,...,k]out

Fig. 6

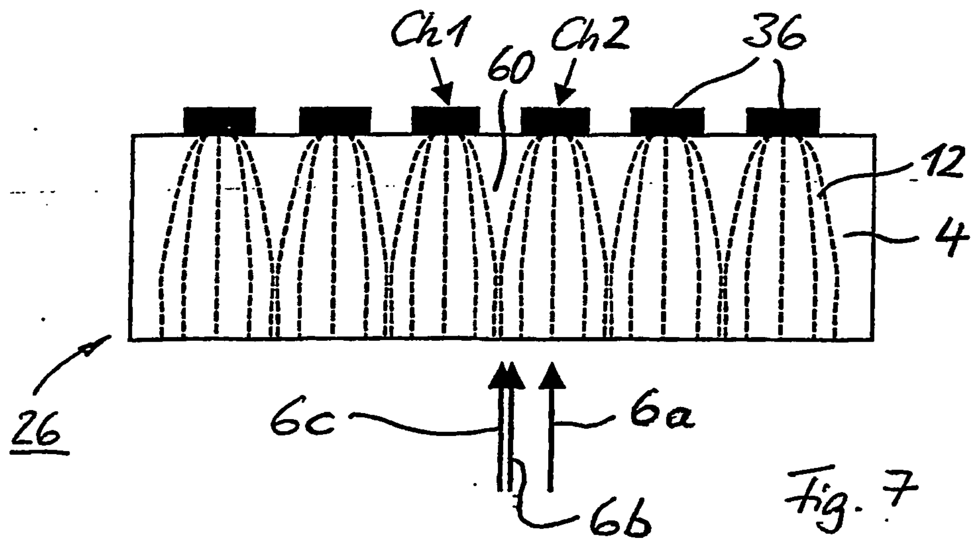
Ch1
Ch2
36
60
12
4
26
6c
6a
6b

Fig. 7

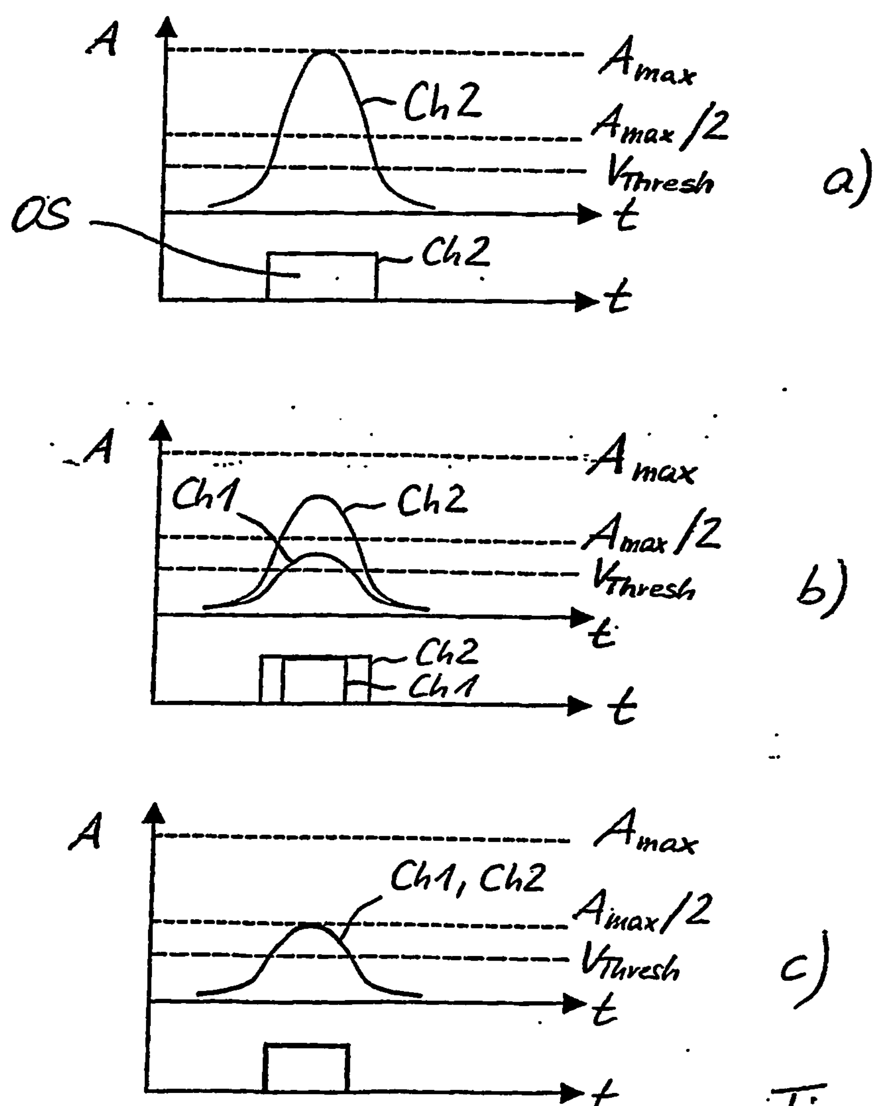
A
A_{max}
Ch2
$A_{max}/2$
V_{Thresh}
t
OS
Ch2
t
a)
A
A_{max}
Ch1
Ch2
$A_{max}/2$
V_{Thresh}
t
Ch2
Ch1
t
b)
A
A_{max}
Ch1, Ch2
$A_{max}/2$
V_{Thresh}
t
t
c)

Fig. 8

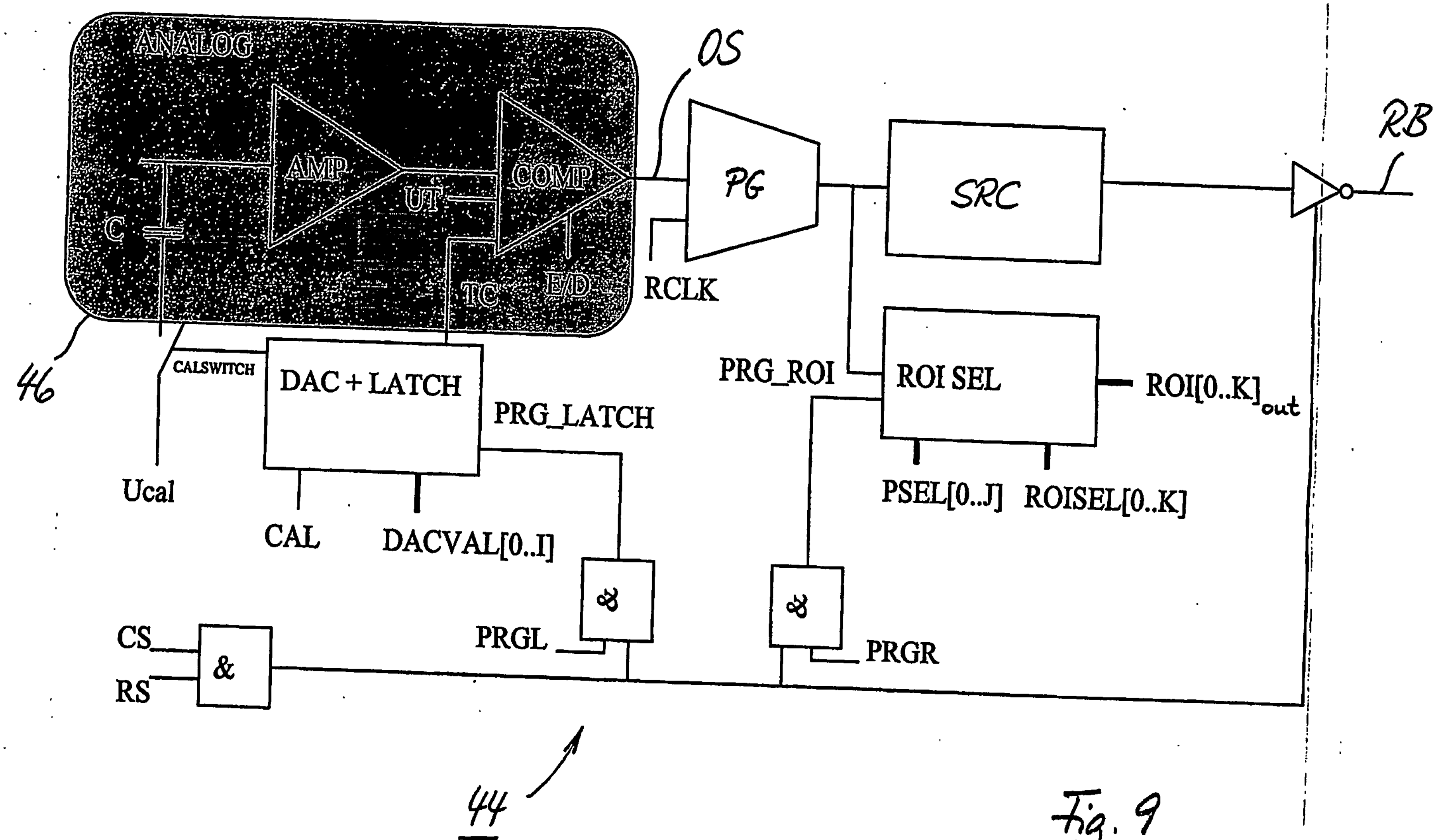
ANALOG
C
AMP
UT
COMP
TC
E/D
OS
PG
RCLK
SRC
RB
46
CALSWITCH
Ucal
DAC + LATCH
CAL
DACVAL[0..I]
PRG_LATCH
PRG_ROI
ROI SEL
ROI[0..K]out
PSEL[0..J]
ROISEL[0..K]
CS
RS
&
PRGL
PRGR
44

Fig. 9